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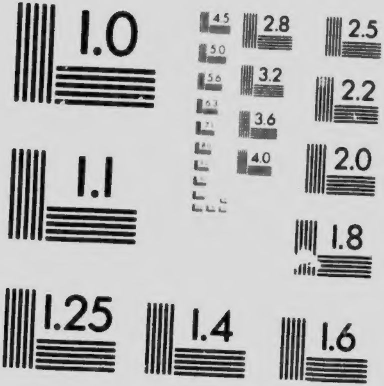

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ELECTRIC FURNACES AS APPLIED TO NON-FERROUS METALLURGY.

BY

ALFRED STANSFIELD.

[Advance copy of Paper read at a meeting of the Institute of Metals, March 29th, 1916.

MONTREAL, 1916

ELECTRIC FURNACES AS APPLIED TO NON-FERROUS METALLURGY*

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Introduction.

The iron and steel trade is so enormous, and recent developments in the production of steel and even pig iron in the electric furnace are so spectacular, that one is apt to overlook the fact that in value—if not in tons—the use of electric furnaces in non-ferrous metallurgy is greater than in the realm of iron and steel. In making this comparison we may perhaps exclude from both sides, the large production of ferro-silicon, ferro-chromium, ferro-tungsten, &c., which are partly ferrous and partly non-ferrous in character.

The table on p. 278 shows approximately the annual production of iron, steel, and the other metals throughout the world, and the extent to which these are produced with the aid of the electric furnace.

In view of the great cost of electrical heat, as compared with fuel heat, one would expect that electrical heating would be employed in metallurgy: (1) for the reduction of very easily oxidizable metals such as sodium, magnesium, and aluminium, which in general require the electrolysis of fused salts for their production; (2) for the reduction of metals such as tungsten and molybdenum, and the metalloid silicon, which need extremely high temperatures for their reduction or fusion; (3) for the reduction of metals like zinc and cadmium, which, although reducible at moderate temperatures, require the complete exclusion of the products of combustion of fuels. One would never have expected, *a priori*, that this costly source of heat would be employed for the production of steel or pig iron.

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* Read at the Annual General Meeting, London, March 29, 1916.

World Production of Metals.

In metric (or long) tons. Mostly for the year 1913.

Pig iron	78,000,000	tons	(50,000 tons electric).
Steel	76,000,000	,,	(200,000 ,, ,,) ¶
Copper *	1,000,000	,,	
Zinc *	1,000,000	,,	
Lead *	1,000,000	,,	
Tin *	‖120,000	,,	
Aluminium *	80,000	,,	(electrolytic)
Chromium *	50,000	,,	(mostly as ferro-chrome)
Nickel *	32,000	,,	
Antimony †	25,000	,,	
Silver *	7,800	,,	
Sodium ‡	5,000	,,	(electrolytic)
Tungsten * §	4,800	,,	(mostly as metal)
Mercury *	3,000	,,	
Silicon ‖	2,000	,,	(silicon metal, not including ferro-silicon)
Gold *	680	,,	
Vanadium §	600	,,	(as ferro-vanadium)
Bismuth *	500	,,	
Molybdenum §	100	,,	(mostly as ferro-molybdenum)
Cadmium *	59	,,	
Calcium ‡	50	,,	
Platinum *	9	,,	

80,000	tons	of aluminium per annum represents	300,000	E.H.P.
200,000	,,	electric steel per annum represents	25,000	,,
50,000	,,	electric pig iron per annum represents	20,000	,,
5,000	,,	sodium per annum represents	10,000	,,
2,000	,,	silicon per annum represents	4,000	¶

It will be observed, in the above table, that aluminium easily takes the first place, as regards the consumption of electrical energy, but on account of the overwhelming scale of siderurgical operations, the electric smelting of iron ores and the production of steel now occupies the second place, if we exclude the production of the ferro alloys.

CLASSIFICATION.

In view of the title of this paper it will be most appropriate to classify the electric furnaces we have to consider according to the kind of operation for which they are to be employed. From this point of view they may be arranged as follows :—

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* *Mineral Industry*, 1914, vol. xxiii. p. 756.

† *Ibid.*, p. 47. The production of antimony in 1913 in China, France, and Hungary was 20,000 tons. In the United States 2,000 tons was produced in the form of antimonial lead, and 2000 tons from old alloys and drosses.

§ The Primos Chemical Company, letter of Dec. 16, 1915. They place the production of tungsten at 4000 tons.

‡ J. W. Richards, letter of Dec. 11, 1915, estimates 5,000 to 6,000 tons of sodium.

‖ F. J. Tone, letter of Dec. 10, 1915, states output of silicon by the Carborundum Company will be 1500 tons for the current year ; there are two other producers.

¶ Complete returns are not available. In 1913 the United States and Germany made 132,000 tons, and in 1914 these countries and Austria made 133,000 tons. *Iron Age*, Jan. 7, 1915.

A. Furnaces for the reduction of metals from their ores.
B. Furnaces for heating, melting, refining, and distilling metals.

Under heading A there are the following classes :—

1. *Electrolytic Furnaces.*—These are used for the production of metals by electrolysis of their fused salts ; aluminium, sodium, potassium, magnesium, calcium, barium, and strontium are produced largely, if not exclusively, in this manner, and other metals such as zinc are occasionally so obtained.

2. *Electrothermic Smelting Furnaces.*—These are used for the production of metals from their ores with the aid of electrically generated heat. The metal is occasionally present in the ore in the native or metallic state, when it merely needs melting to separate it from the gangue ; but usually the metal is found as an oxide or other chemical compound from which it must be liberated by a chemical reaction involving the use of carbon or other reagent in addition to the necessary electrical heat.

Some metals (and semi-metals), such as silicon, chromium, tungsten, and titanium, require so high a temperature for their reduction or fusion that they can only be obtained (directly or indirectly *) from the electric furnace. Some metals (like zinc) can be reduced by means of fuel heat, but only in externally fired retorts, as the products of combustion must be entirely excluded. For these metals electrical heat seems especially appropriate, as it can be produced within the charge to be heated, and there are no products of combustion. Another class of metals, such as copper, nickel, lead, tin, silver, and gold, can be smelted readily by ordinary fuels, and for them the more costly electrical heat will only occasionally be employed.

Under heading B there are the following classes :—

1. *Heating Furnaces.*—Electric muffles and similar furnaces for the heat-treatment of metals, enamelling, &c. These are usually intended for moderate temperatures.

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* As aluminium is produced in the electric furnace, the alumino-thermic production of metals is indirectly due to this appliance.

2. *Electric Welding, Soldering, and Cutting Appliances.*—In these the metals that are to be united or divided are heated electrically.

3. *Electric Melting Furnaces.*—Some of their uses are: the melting of cathode copper, the melting and alloying of brass or bronze, and the melting and refining of gold precipitate.

The electric furnaces employed in non-ferrous metallurgy may be discussed conveniently under the headings already enumerated.

Electrolytic Furnaces.

The production of metals by electrolysis depends on the direct application of electrical energy to separate these metals from elements with which they are chemically combined. It differs in this respect from other smelting methods in which, as a rule, some reagent is employed, and an exchange effected whereby some cheaper substance, such as carbon, is sacrificed to obtain the more valuable metal. Carbon, in the form of coal, is usually cheaper than the electrical energy that would be needed to separate it from its combination with oxygen, and therefore it is usually cheaper to reduce a metal from its oxide electrothermally, with the aid of carbon, than electrolytically. Some metals cannot conveniently be produced electrothermally, and for these it is necessary to employ electrolysis. Such metals have so strong an affinity for oxygen that it is impossible to obtain them by electrolysis in aqueous solutions, and fused salts must be employed as electrolytes. We may therefore say in general that electrolytic furnaces are used for the production of those metals that cannot conveniently be produced by thermal or electrothermal methods. In some electric furnaces, such as the aluminium furnace, the oxidation of carbon is employed to assist the reaction, and in other cases purely thermal methods are used to obtain the metal in the form of a compound from which it can readily be liberated by electrolysis.

Aluminium.—This metal is distributed very widely, as it constitutes some 15 or 20 per cent. of most clays, but, owing to the expense involved in extracting it from clay, the richer ore, bauxite, is alone employed. Bauxite is an impure hydrated oxide of aluminium, and from this the pure oxide Al_2O_3 is prepared.

Alumina, dissolved in a fused fluoride of sodium and aluminium, is decomposed by electrolysis according to the thermal equation :

$$\underset{392,600}{Al_2O_3} + 3C = \underset{87,480}{3CO} + Al_2.$$

Net heat needed, 305,120 calories.

This reaction could be carried out either electrolytically or electrothermally, and should require exactly the same amount of energy by either method. As, however, the electrolysis is effected at about 800° C., while the electrothermic reduction would need a temperature of about 1800° C., the heat carried off by the products of the reaction would be far greater in the second case and the efficiency would consequently be less. In addition there is the unfortunate fact that at high temperatures the metal combines with carbon to form a carbide from which it cannot readily be released.

Another compound of aluminium, the chloride Al_2Cl_6, can be used for electrolysis when melted with sodium chloride, forming the double salt $2NaCl,Al_2Cl_6$. The reaction would be represented by the thermal equation :—

$$Al_2Cl_6 = Al_2 + 3Cl_2.$$

323,600 calories.

The energy required for decomposing the chloride by electrolysis is somewhat less than is needed for decomposing alumina into its elements, but is more than is needed for reducing alumina to metal with the assistance of carbon. In view of this there is nothing to gain in using aluminium chloride in place of the cheaper substance alumina.

The standard method for producing aluminium involves first the production of pure alumina from the bauxite ore. This is essential because any iron, silicon, &c., remaining in the alumina would find their way into the resulting aluminium.

Alumina can be prepared by several methods. The oldest method, that of Bayer, consists in digesting calcined bauxite in a strong solution of caustic soda under pressure which dissolves the alumina. After dilution and filtration, to remove ferric hydroxide, some precipitated aluminium hydroxide is added, which serves to precipitate about 70 per cent. of the alumina present in the solution. This is washed and dried for use in electrolysis, and the solution reconcentrated and used again.

Another method, that of Hall, consists in mixing the calcined bauxite with enough carbon or aluminium to reduce to the metallic state the iron and silicon present. The mixture is then melted in an electric furnace and the resulting fused alumina is crushed and separated mechanically from the entangled shots of ferro-silicon. This method has not been found entirely satisfactory because the resulting alumina is not readily soluble in the electrolyte.

A still later process, that of Serpek, depends on the formation of a nitride of aluminium by heating bauxite and carbon to about 1800° C. in a current of nitrogen—

$$Al_2O_3 + 3C + N_2 = 2AlN + 3CO.$$

Any silica present in the bauxite is reduced to silicon and volatilized. The resulting nitride is decomposed by means of water yielding ammonia which can be used for producing ammonium salts, and alumina for the production of aluminium. The Serpek process has not been employed as yet on the large scale, but will probably be utilized in the near future. The Bayer process is now generally in use.

A plant for the production of aluminium * has been erected recently by the Southern Aluminium Company at Whitney, N.C. The furnaces are iron tanks 5 feet high, 9 feet wide, and 12 feet long in outside dimensions. These are lined with a course of firebrick and an inner lining of carbon, leaving a working cavity 4 feet by 8 feet and 20 inches deep. Each of these furnaces is expected to take 20,000 amperes at 7 volts, corresponding to 140 kilowatts, and should produce 300 lb. (135 kilogrammes) per day. Seventy furnaces are connected in series, corresponding to an electromotive force of 500 volts. The plant will contain six of these units, so that about 400 furnaces will be in operation at the same time, corresponding to a production of 44,000,000 lb. of aluminium per year. The power consumption will be about 1¼ kilowatt per 1000 lb. per annum.

The general nature of the operation is well known; the carbon lining of the furnace is connected by iron bars to the metal casing and forms the cathode. The anodes are made of

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* *Mineral Industry*, 1914, vol. xxiii. p. 18.

petroleum coke containing less than 1½ per cent. of ash, and these are adjusted so that their height above the cathode is between 2 and 2½ inches. The molten electrolyte, consisting in the main of cryolite, is covered with a layer of carbon which serves to retain the heat, and above this is fed the alumina, which is stirred in from time to time as required by the bath.

Sodium.—This metal is employed very largely in the chemical industry. At one time it was obtained by heating sodium carbonate with charcoal and chalk in iron retorts; the sodium so reduced coming off as a vapour and being condensed and finally collected beneath a mineral oil. At the present time the production is wholly by electrolysis of fused sodium salts. Many processes have been tried, but at present the Castner process and that of the Virginia Electrolytic Company are alone in use.* In the United States the Niagara Electro-Chemical Company † are operating the Castner process in which fused caustic soda is electrolyzed, and the Virginia Electrolytic Company is operating its own type of furnace, devised by Seward and Kugelgen, for the production of sodium by electrolysis of fused sodium chloride. The present output in the United States from these two firms is some 3000 tons of sodium per annum, while the production in the whole world must be some 5000 to 6000 tons.‡

Potassium.—This metal is very similar to sodium in its properties and methods of production. It is obtained in small quantities by electrolysis of fused caustic potash. In view of the high price of potash salts and of the fact that metallic sodium serves most, if not all, of the purposes for which potassium could be employed, the latter metal is not made on a very considerable scale.

Calcium.—The salts of this metal are very abundant, but the metal itself, while obtainable by electrolysis of the fused chloride, has no important mechanical properties, but is useful as a reducing agent. It is used to a moderate extent in the metallurgy of steel, as it serves not only to deoxidize but also to absorb nitrogen. Calcium heated in a current of hydrogen yields a hydride, CaH_2, which can be employed very conveniently for the production of hydrogen and is known as hydrolith. The production of calcium by electrolysis of its fused chloride[*] is peculiar in that a very high current density must be maintained at the cathode. This condition is obtained by inserting a rod forming the cathode just beneath the surface of the electrolyte and withdrawing this steadily as the calcium deposits on the end of it, thus building up a rod of metallic calcium which is protected from oxidation by the salt which chills around it.

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* *Mineral Industry*, 1914, vol. xxiii. p. 665.

† A. Stansfield, "The Electric Furnace," 1914, p. 379.

‡ J. W. Richards, letter of Dec. 11, 1915.

Calcium is made commercially at Bitterfeld in Germany by the Griesheim Gesellschaft. The world's production is about 50 tons a year and the price in normal times about three dollars (12*s.* 6*d.*) a pound.[†]

Magnesium.—This metal, which is closely allied to calcium, is of use mechanically as well as for chemical purposes. It is a beautiful white metal resembling aluminium, but having even a smaller specific gravity of 1·74. Its melting point is 750° C. Magnesium is produced, in general, by electrolysis of the fused chloride.[‡] and before the war it was made largely, if not entirely, in Germany, where there are immense deposits of salts containing magnesium chloride.

When war was declared it became impossible to obtain from Germany either the metal or the carnalite from which to prepare it, and at the same time there arose a great demand for magnesium for military purposes. Investigations were started in the United States and in Canada with a view to making magnesium commercially, and the writer made small scale experiments in February and March 1915, and worked out the design of a furnace in which, after overcoming the usual difficulties during the initial stages, magnesium has been produced in commercial quantities. A plant using this type of furnace is now in regular operation in Canada. Two firms are now working on the production of magnesium in the United States[§] and one in England.

Magnesium is used largely for the production of illuminating powders for photographic purposes, but the war has led to a great extension of its use as an illuminant. Magnesium is also employed as a deoxidizer in the production of bronzes and similar alloys, and recently it has been used with aluminium as an alloy where extreme lightness is desirable.

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[*] F. C. Frary, "Efficiency in the Electrolytic Production of Metallic Calcium," *Transactions of the American Electrochemical Society*, 1910, vol. xviii. p. 117; A. R. Johnson, "The Electrolytic Preparation of Calcium," *Transactions of the American Electrochemical Society*, 1910, vol. xviii. p. 125.

[†] J. W. Richards, letter of Dec. 11, 1915.

[‡] S. A. Tucker and F. L. Jouard, "The Electrolytic Preparation of Magnesium," *Transactions of the American Electrochemical Society*, 1910, vol. xvii. p. 249; F. C. Frary and H. C. Berman, "The Formation of Magnesium Sub-oxide in the Electrolytic Preparation of Magnesium," *Transactions of the American Electrochemical Society*, 1915, vol. xxvii. p. 209.

[§] J. W. Richards, letter of Dec. 11, 1915.

Barium, Strontium, Cerium.—These metals are produced in small quantity by electrolysis of their fused chlorides. An elaborate research into the production and properties of cerium has recently been made by A. Hirsch.*

The incandescent gas mantle industry requires large quantities of the rare element thorium. This is obtained from monazite, which contains other rare elements such as cerium and lanthanum in far larger proportion than the thorium for which the monazite was at first treated. A use for these elements has been found in the production of the "pyrophoric" alloys so largely used for gas and cigar lighters. A mixture of anhydrous chlorides of these rare metals is electrolyzed, and the resulting alloy, known as "Mischmetall," is alloyed with iron in the proportion of 65 per cent. of the alloy to 35 per cent. of iron to form the pyrophoric alloy "Auer metal." Many other pyrophoric alloys have been prepared, most of which include the cerium alloy "Mischmetall." Some 200 tons per annum of the cerium oxides are employed in the manufacture of this and similar pyrophoric alloys.†

Zinc.—The electrothermic production of zinc in the electric furnace will be discussed in a different part of this paper, but reference must be made here to the electrolysis of fused zinc chloride. This has formed part of a process for the treatment of sulphide ores of zinc and other metals by chlorine, in which the sulphides, in a state of fusion, were converted into the chlorides, and these were separated and purified so as ultimately to leave zinc chloride only, which was reduced by electrolysis. This process, the Swinburne and Ashcroft chlorine smelting process,‡ is not at present in use, and electrolysis of the fused chloride has only a very limited application.

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* A. Hirsch, "The Preparation and Properties of Metallic Cerium," *Transactions of the American Electrochemical Society*, 1911, vol. xx. p. 57.

† S. J. Johnstone, "The Rare Earth Industry," 1915, p. 30.

‡ Swinburne and Ashcroft process, *Electrochemical and Metallurgical Industries*, 1905, vol. iii. p. 63.

ELECTROTHERMIC SMELTING FURNACES.

These furnaces are employed for the reduction of metals from their ores. The ores treated are frequently oxidized and their reduction is effected in general by reaction of these oxides with carbon with the aid of electrically generated heat. Compared with fuel-fired furnaces the electric furnace has the advantage that air and the products of combustion of fuels can be completely excluded, and that higher temperatures can be obtained. These furnaces are therefore specially useful for the reduction of metals like chromium, tungsten, titanium, and the semi-metal silicon, which can only be reduced with difficulty. These metals may perhaps be included in the class of ferrous metals, especially as they are generally produced in the form of a ferro-alloy, and they will therefore be discussed briefly. Other metals, such as zinc, copper, lead, and tin, will be discussed more fully.

Silicon.—This is an interesting metalloid produced by the Carborundum Company at Niagara Falls. Mr. Tone, to whom the commercial production of this metal can be attributed, informs the writer that their output is 1500 tons per annum. Other producers of silicon are the Hafslund Sulfitfabrik, Hafslund, Sarpsbörg, Norway, and the Bosniche Elektricitats Gesellschaft, Jaice, Bosnia, Austria. This substance is used in steel-making and also in the chemical industry owing to its power of resistance to acids. It has been employed instead of aluminium for the reduction of metals by the Goldschmidt process. A recent development is its use for the production of hydrogen.

It has been estimated that silicon forms 27·4 per cent. of the contents of the solid crust of the earth, so that there is no difficulty in obtaining the ore of this element. Silicon is reduced from its oxide, silica, by the action of carbon in the electric furnace at a temperature which has been stated to be 1460° C., but in practice a higher temperature is no doubt employed. Serious difficulties are encountered owing to the volatility of silicon and the formation of silicon carbide, SiC, at high temperatures. The reduction of silicon was first effected in resistance furnaces, but now suitably designed arc furnaces are found to answer the purpose.

Ferro-silicon.—Very large quantities of this ferro-alloy are made in the electric furnace for use in the steel industry, the usual grades being 50 per cent., 75 per cent., and 90 per cent. Before the war the highest production on the American continent was about 75 tons a day or 25,000 tons per annum, but at the present time the production has increased enormously, reaching perhaps 220 tons daily or 80,000 tons per annum, of which 50 to 60 tons daily or 20,000 tons per annum are produced in Canada.

Tungsten.—Some 4000 tons of this metal are produced per annum largely in the metallic form, and mostly by means of the electric furnace. Tungsten is used for the production of special steels and also for electric lamps.

For steel-making an 80 per cent. ferro-tungsten is largely used, and this is manufactured on a large scale at the Girod works near Albertville, Savoie, France, while in the United States the metal is produced at the present time in as pure a form as possible for use in lamp-making. It seems probable, however, that 80 per cent. ferro-tungsten will again be made in America in view of the phenomenal demand for tool steel at the present time.

Molybdenum.—About 100 tons per annum of this metal are produced in the electric furnace, mostly as ferro-molybdenum.

Molybdenum can be obtained from its sulphide ore, molybdenite, by roasting this to oxide and then reducing the oxide in an electric furnace, either alone to produce the pure metal, or with the addition of iron for the production of ferro-molybdenum. Owing to the difficulty of roasting molybdenite completely, and the volatility of the oxide, molybdenite is often smelted directly with the addition of lime and carbon. O. W. Brown * has shown that the latter method can be carried out very satisfactorily in an electric furnace, the reaction being as follows :

$$MoS_2 + 2CaO + 2C = Mo + 2CaS + 2CO.$$

The resulting metal contained about 1·5 per cent. each of iron and carbon, but the sulphur was very low and in no case over 0·25 per cent.

Molybdenum would be used more largely than it is in steel-making, as a substitute for tungsten, if it were not for the seams that it causes in the steel ingots. It has been stated that only one-quarter of all the molybdenum steel produced is free from seams, and this makes the cost of production so high as to be almost prohibitive.*

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* O. W. Brown, "Reduction of Metal Sulphides," *Transactions of the American Electrochemical Society*, 1906, vol. ix. p. 109.

Vanadium.—Some 1500 tons of ferro-vanadium, averaging 40 per cent. of the metal, are produced per annum. In the United States the alumino-thermic process is employed, but Girod in Europe, and possibly others, employ the electric furnace.

Chromium.—This is obtained mostly in the form of ferro-chromium by means of the electric furnace, several thousand tons being made per year,† the figure of 50,000 tons per annum of chromium being quoted by one writer. Ferro-chrome is produced in the United States and also in Europe, notably at the Girod works in France.

Titanium.—This element is found widely distributed in titaniferous iron ores, as well as in the mineral rutile. The ores are smelted in the electric furnace for the production of ferro-titanium, using in general a high titanium iron ore, iron turnings, and coal or coke.

The use of ferro-titanium in steel-making and in the iron foundry has been very largely advertised, and ferro-titanium has been used in the manufacture of as much as 200,000 tons of steel rails in a year. Titanium is used for the purpose of cleaning the steel as it combines both with oxygen and nitrogen. The value of ferro-titanium in steel-making has, however, been questioned, and it is difficult to obtain definite information on this point from impartial persons.

A copper-titanium alloy has also been produced and has been found useful as an addition in making copper castings.

Zinc.—Much interest has centred, for a number of years, on the electrothermal smelting of zinc ores, in spite of which no satisfactory process has yet been developed. The normal process for obtaining zinc from its ores, consists in roasting them very completely, and then reducing to the metallic state the zinc oxide so obtained, by mixing the roasted ore with about half its weight of anthracitic coal and heating the mixture to about 1300° C. or 1400° C. in retorts made of fireclay. The process leaves much to be desired, because the heat is applied uneconomically, as it has to pass through the walls of the retorts, and in consequence these retorts must be relatively small and much hand labour is required in treating the ore. The metallurgy of zinc appears, therefore, to be in a backward state compared, for example, with that of copper, for thousands of tons of copper ore can be smelted per day in a single furnace. It must be remembered, however, that the copper ore may contain as little as 2 per cent. or 3 per cent. of that metal, while zinc ores are concentrated as a rule until they contain at least 50 per cent. of zinc before they are sent to the smelter. Moreover, the details of zinc smelting have been worked out so thoroughly that the cost per pound of metal is now very reasonable, being from 1c. to 2c. when smelting rich ores with natural gas—a cost decidedly below that at which copper is usually obtained from its ores.

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* R. Turnbull, letter of Dec. 29, 1915.

† *Mineral Industry*, 1914, vol. xxiii. p. 765.

Whatever may have been the cause, the electric smelting of zinc ores has held the attention of metallurgists for a long time, and during recent years a large amount of work has been done on the problem of treating, not merely the high grade ores that are easily distilled in the Belgian zinc retort, but also the low grade and complex ores that can hardly be treated at all by existing methods.

In considering the electric smelting of zinc ores, the first point to make clear is the great difference between the old practice and the methods attempted by the electro-metallurgist. In the Belgian retort, the charge of roasted ore and coal is heated gradually for a number of hours, driving off first the moisture and the hydrocarbons from the coal, then the carbon dioxide resulting from the reduction of easily reducible metals such as iron and lead, and finally, when a temperature of over 1000° C. has been reached, the zinc vapour itself with its equivalent of carbon monoxide. Under these conditions the condensation of the zinc vapour is satisfactory, and a large proportion of the metal is obtained in the molten condition. This operation could no doubt be reproduced in an electric furnace, and would have the advantage that somewhat larger retorts could be employed; but the electric furnace inventor is not content with so moderate an attainment, he wishes to change the whole process from the present step by step method to a continuous smelting operation in which the ore and reducing carbon shall be fed into the furnace at one point, the zinc shall flow out of the condenser, in the molten state, at another point, the slag shall be tapped off from a third point, and lead bullion, carrying any gold and silver values, shall flow out at a fourth opening in the furnace. The task thus set is by no means easy; if the ore mixture goes without preparation into the smelting chamber the moisture, hydrocarbons, and carbon dioxide will come off in admixture with the zinc vapour and carbon monoxide, and the zinc will condense from this mixture mostly in the form of a blue powder; that is to say, as a solidified mist of minute drops of metallic zinc containing a certain small proportion of zinc oxide and other extraneous substances. By a preliminary heating of the ore mixture in a separate chamber the moisture, hydrocarbons, and carbon dioxide can be removed to a large extent, but it is difficult to effect their complete removal; there is still the possibility of sulphur dioxide being included in the mixture of gases, and finally trouble is caused by the volatilization of carbon and even silicon, which will contaminate the gas mixture that enters the condenser.

A point that has not been fully realized by many writers on the subject is the physical condition of the condensation which is necessary for a satisfactory result. The zinc may condense on the walls of the condenser, in which case the condensed droplets will grow until they become large enough to flow together. If, on the other hand, the zinc condenses on floating particles of dust, carbon, &c., away from the walls of the condenser, the droplet that forms on each particle will fall to the bottom of the retort before becoming large enough to coalesce with other droplets, and this is no doubt the manner in which blue powder is commonly formed. The writer was engaged for some years in a research carried out at McGill University for the Dominion Government with a view to finding a process for treating the low grade and complex zinc ores of British Columbia, and has had ample opportunity for appreciating the difficulties to be overcome before a successful electric furnace process can be developed.

One difficulty, inseparable from the ordinary process of zinc smelting, is the need for an almost perfect roast of the sulphide ore, as a preparation for the distillation process. The ore must be roasted until it contains not more than about 1 per cent. of sulphur, an operation that entails a considerable expense both in labour and fuel. The electric furnace process, on the other hand, holds out the hope that this roasting operation can be dispensed with, or at least that it need not be nearly so thorough. This possibility depends on the removal of the sulphur in the electric furnace in combination with metallic iron, or more cheaply with calcium supplied in the form of lime. O. W. Brown and W. F. Oesterle[*] have studied the latter reaction, and find that it takes place very completely, in the electric furnace, according to the equation—

$$ZnS + CaO + C = Zn + CaS + CO.$$

In Norway and Sweden the electric smelting of zinc ores has been carried out commercially for some years. At Trollhättan in Sweden a very large plant is in regular operation, but the owners are unwilling to give access to visitors, and the only information that has been published is the report by Mr. Harbord[†] made in the year 1911. Judging by this report it seems that their success has been only partial, that a large amount of blue powder is made which must be resmelted with further quantities of ore, and that, in consequence, the consumption of electrical energy is so great that the process is only economical in view of the unusually cheap rates at which electrical power can be obtained in that district.

On this continent a great deal of work has been done by W. McA. Johnson,[‡] who has published many papers in regard to the subject, and has carried out smelting operations, on a considerable scale, at a plant in Hartford, Connecticut. This process has been investigated by the Dominion Government with a view to its application in British Columbia, but apparently complete success has not yet been reached.

A word may be added with regard to the present situation in Canada. There are here large quantities of low grade and leady zinc ores, that can only with difficulty be concentrated so as to produce high grade lead and zinc ores respectively. In the past there has been a moderate production of zinc concentrates for export to American smelters; the treatment charges and high freight rates serving to prevent any very extensive development in this direction. Some 7000 to 9000 tons of zinc ores and concentrates, containing about 3000 to 4000 tons of zinc, have been shipped annually in recent years. At the beginning of the war the smelters in the United States declined to take further shipments of zinc ores from British Columbia, and there was at that time in Canada a shortage of zinc for use in manufacturing ammunition and a quantity of zinc ore that could not be disposed of. A Commission, of which the writer was a member, was appointed, by the Minister of Militia and Defence, to look into this matter on behalf of the Government. The Canadian Shell Committee needed pure zinc for use in the manufacture of cartridge brass, and it was impossible to obtain such zinc from the British Columbia ores by any distillation process, whether in the Belgian retort or in the electric furnace. It was therefore necessary to turn to hydro-metallurgy, and after a large amount of experimental work a process has been developed at the works of the Consolidated Mining and Smelting Company at Trail, B.C., and at some other smelters', which is a modification of the well-known Létrange process, the ore being roasted, leached with sulphuric acid, and the resulting zinc sulphate solution electrolyzed with insoluble anodes. Within the last few months a large plant has been built at Trail, costing perhaps 1,000,000 dollars, and capable of producing 30 or 40 tons of electrolytic zinc per day, which should meet in large measure the present requirements for cartridge brass in this country. Similar work is going on at Anaconda in Montana and at Welland in Ontario.

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[*] O. W. Brown and W. F. Oesterle, "The Electric Smelting of Zinc," *Transactions of the American Electrochemical Society*, 1905, vol. viii. p. 171.

[†] F. W. Harbord, "Zinc Smelting at Trollhättan," *Engineering and Mining Journal*, Feb. 10, 1912, p. 314.

[‡] W. McA. Johnson, "The Art of Electric Zinc Smelting," *Transactions of the American Electrochemical Society*, 1913, vol. xxiv. p. 191.

This development was undoubtedly the best under the existing circumstances, but it must not be supposed that it disposes of the possibility of smelting these ores in the electric furnace. While recognizing the serious difficulties which stand in the way of a successful commercial use of the electric furnace for smelting zinc and zinc-lead ore, the writer still believes that this will in time be accomplished and that in favourable localities a large industry will be built up on the electric smelting of zinc.

Copper.—In view of the satisfactory nature of the existing methods of smelting copper ores, the electric furnace does not offer any great advantages for their treatment. For the smelting of oxidized ores of copper where a simple reducing fusion is required, the electric furnace is quite appropriate and can be used in those comparatively rare cases where fuel is unusually expensive and electrical power unusually cheap. Such cases exist and no doubt will lead to a small development of electrical copper smelting. The large majority of copper ores, however, are sulphides, and the blast-furnace at present employed to smelt them has two functions to perform—one of which is to remove by oxidation a large proportion of the sulphur present in the original ore, so that a sufficiently high grade of copper matte can be produced. In other words, the typical process of copper smelting in the blast-furnace is a pyritic or semi-pyritic smelting. The electric furnace does not apparently lend itself to an oxidizing smelt, and it therefore seems particularly unsuitable for the treatment of these sulphide ores, which in any case can be smelted with the consumption of a very small proportion of coke. It has been pointed out, however, that there is one case where electrical heat may very well be used as an auxiliary in the blast-furnace for smelting copper ores. The pyritic process depends on the use of so little fuel that the oxygen in the blast shall not be used up in that way and is therefore available for the oxidation of sulphur and iron in the ore. The heat produced by this oxidation is just sufficient for the purpose, but the process is not very easily carried out. It is possible that a furnace could be constructed in which the ore could be smelted without the addition of any fuel, and the small amount of additional heat required to keep the furnace in satisfactory operation could be supplied electrically, below the zone at which the blast enters from the tuyeres. At the present time this is merely a suggestion and has not been worked out in practice.*

Nickel.—This metal is found in enormous quantities in Canada in the form of a sulphide of iron, copper, and nickel, and for the treatment of this class of ore the existing methods seem so suitable that very little room is left for electric furnace processes. W. L. Morrison † has, however, made some interesting experiments at the plant of the Consolidated Nickel Company at Webster in North Carolina on the smelting in the electric furnace of a hydroussilicate of magnesium and nickel; this ore being essentially oxidized lends itself to the reducing fusion which is typical of the electric furnace. The Canadian ferro-nickel ores, when sufficiently low in copper, can be smelted, after roasting, for the production of a ferro-nickel pig which in turn can be used for the production of nickel steel. The production of the ferro-nickel pig has been carried out in the electric furnace at the plant of the Lake Superior Power Corporation at Sault Ste. Marie, Ontario.* This operation, however, belongs rather to ferrous-metallurgy and is somewhat outside the province of this paper.

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* D. A. Lyon and R. M. Keeney, "The Smelting of Copper Ores in the Electric Furnace," *Transactions of the American Institute of Mining Engineers*, 1913, vol. xlvii. p. 233.

† W. L. Morrison, "Electric Furnace Treatment of Nickel Ores and the Development of a Commercial Process," *Transactions of the American Electroche* [illegible] *ciety*, 1911, vol. xx. p. 315.

Lead.—In view of the great ease with which lead can be reduced from its ores in ordinary furnaces there seems to be little room for an electric furnace treatment. It has seemed possible, however, that electric smelting might be applied to the treatment of high grade lead ores whose reduction in the blast-furnace is wasteful on account of the heavy losses by volatilization. Difficulty will be found in any such process because the high grade ores can scarcely be roasted sufficiently well without raising them to a temperature at which fusion ensues, and the electric furnace, as ordinarily constructed, is not suitable for carrying out an oxidizing fusion. The writer had recently occasion to attempt to smelt some high grade galena in a small electric furnace, after roasting it by hand in a reverberatory furnace, and became painfully aware of these inherent difficulties. The roasted ore contained so much sulphur that it was necessary to add metallic iron to liberate the lead in the fusion furnace, and when attempting to do this by electrical heat it was found that if an arc was formed between the electrodes and the charge, the volatilization of lead was very serious; while if the electrodes were immersed in the melted charge the resistance was so low that it was impossible to run the furnace satisfactorily, a current of some 2000 amperes requiring no more than 10 volts. The trouble was, of course, due in large measure to the formation of a fused matte or sulphide of iron and lead, having a very high electrical conductivity. It would, no doubt, be possible to avoid this difficulty, but under the circumstances the attempt was discontinued.

Antimony.—The production of this metal in ordinary furnaces is carried out on a small scale and is somewhat complicated in character. As the ore is usually a sulphide we are confronted with the difficulties already mentioned in the case of lead ores, but it may very well be that some electric furnace process can be devised that will compare favourably with the existing methods. The writer understands that a smelter in New Brunswick in Canada is about to take up the use of electric smelting for the ores of this metal.

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* F. A. Sjostedt, "Electric Smelting Experiments for the Manufacture of Ferro-nickel from Pyrrhotite," *Transactions of the American Electrochemical Society*, 1904, vol. v. p. 233.

The existing methods for extracting antimony from its sulphide ores are: (1) Fuse the stibnite with metallic iron, thus producing metallic antimony and iron sulphide. (2) Volatilize the sulphide in a shaft furnace, oxidize it to Sb_2O_3, collect the oxide in filter bags, heat it in a reverberatory furnace with charcoal and soda, thus producing metallic antimony. (3) Electrolysis of antimony sulphide dissolved in an aqueous solution of sodium sulphide. O. W. Brown * has tried to obtain antimony by heating the sulphide with lime and carbon, but without complete success. In some of his experiments an electric furnace was employed, and the resulting metal was distilled and recovered in an external condenser. C. G. Fink † has carried this idea further by using the Arsem vacuum furnace, and finds that stibnite ores can be treated successfully by heating them in this furnace with limestone and carbon, collecting the distilled antimony in a very pure condition in a condenser. The reaction is given by the equation:

$$Sb_2S_3 + 3CaCO_3 + 6C = 2Sb + 3CaS + 9CO.$$

A similar process has been used for recovering antimony from the anode slimes of electrolytic refineries.

In view of the present shortage of antimony, which is used in the production of shrapnel bullets, it would appear worth while to pay further attention to the electric furnace method of smelting.

In this connection it may be pointed out that in non-ferrous metallurgy there will no doubt, in course of time, be many processes and furnaces devised for the electric smelting of such ores, but there are many problems to be solved and difficulties to be met in regard to each case, and we cannot expect that

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* O. W. Brown, "Reduction of Metal Sulphides," *Transactions of the American Electrochemical Society*, 1906, vol. ix. p. 113.

† C. G. Fink, "Vacuum Furnace Metallurgy," *Transactions of the American Electrochemical Society*, 1912, vol. xxi. p. 452.

electric smelting can be applied successfully in any wholesale manner. Each metal, and in some cases each ore, may need separate treatment.

Tin.—Ores of tin when smelted by ordinary processes consist essentially of the oxide of this metal, and have usually been concentrated so as to contain a large percentage of tin. Being oxidized, these ores lend themselves to smelting in the electric furnace, and in view of the high price of tin and of the consequent importance of reducing to a minimum losses both by volatilization and by imperfect reduction, the metallurgy of tin appears to afford a useful field for electric furnace operations. Some work has been done in England * on the smelting of tin ores and the results obtained seem extremely satisfactory. In America, also, work has been done on electric tin smelting, but in this case it has been the dross rather than the tin ore that has mostly been smelted.†

R. S. Wile ‡ recommends silicious slags for use in the electric tin furnace. Such slags have a high electrical resistance, and thus a temperature of 1600° C. and upwards can be reached. Under these conditions iron is completely slagged off, while the losses of tin in the slag are less than 0·5 per cent. For smelting dross the slag should consist of one part each of soda and lime and four parts of silica.

A Bolivian tin ore, containing—

Sn . . .	63·23	per cent.	S . . .	0·48	per cent.
Fe_2O_3 . . .	4·48	„	As . . .	0·31	„
Al_2O_3 . . .	0·26	„	Sb . . .	0·14	„
Cu . . .	0·54	„	CaO . . .	0·60	„
Pb . . .	0·93	„	SiO_2 . . .	6·96	„

was smelted electrically in the Wile furnace with the addition of lime and silica to make a suitable slag that should not be too heavy with iron. The slag contained 0·45 per cent. of tin, the loss of tin by volatilization was 0·6 per cent., and the metal produced was 99·7 per cent. pure, which compares very favourably with metal produced from the same ore in the reverberatory furnace, which only contained 95 per cent. of tin. The power consumption was 500 kilowatt-hours per ton of ore.

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* John Harden, "Electric Tin Smelting in Cornwall," *Metallurgical and Chemical Engineering*, 1911, vol. ix. p. 453.

† R. S. Wile, "Reduction of Tin Dross in an Electric Furnace," *Transactions of the American Electrochemical Society*, 1910, vol. xviii. p. 203, and 1914, vol. xxvi. p. 252.

‡ Letter from R. S. Wile of December 27, 1915.

The Wile furnace for smelting tin ore and dross consists of a circular crucible with arched roof through which the electrodes enter, dipping into the slag. A central ore chute serves to preheat the charge and to prevent losses of metal by volatilization, as the unsmelted ore forms an effective condenser and filter for the metallic vapour coming up from the smelting chamber.

Silver and Gold.—The electric furnace has not been applied for smelting the ores of these metals, but for treating precipitates and concentrates of the precious metals. The advantages offered by the electric furnace are cleanliness, compactness, and the possibility of a more complete recovery of these valuable metals, any small saving in the recovery being amply sufficient to offset the cost of the electric heat.

W. P. L. Lass * has described an interesting application of the electric furnace at the Alaska-Treadwell cyanide plant. The auriferous by-products from the Tavener refining process, which were at one time treated in a blast-furnace, are now smelted with additions of old reverberatory hearths, litharge, coke and scrap iron in a simple electric furnace 14 inches in internal diameter and 20 inches high. The power used is 35 kilowatts, and amounts to 1000 kilowatt-hours per ton of material charged. The gold is collected in lead bullion, and the operation is more economical than one carried out in the blast-furnace, because of the smaller losses by dusting and volatilization, and the better extraction of values from the slag.

ELECTRIC HEATING FURNACES.

Under this heading may be considered electric muffles, crucible furnaces, and similar appliances for electrical heating. In general these are all resistance furnaces, being heated by means of solid resistors.

A large number of such furnaces have been devised for experimental and laboratory work, among which may be mentioned :

1. Tube and crucible furnaces which are heated by a spiral of platinum wire. These can be heated to a temperature somewhat below the melting point of platinum, and are very satisfactory

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* "Gold Refining with an Electric Furnace," *Metallurgical and Chemical Engineerin* 1915, vol. xiii. p. 566; and *Transactions of the American Institute of Mining Enginee* 1915.

for chemical operations that do not need very high temperatures. The high cost of platinum has led to the use of :

2. Furnaces heated by nichrome and other less expensive resistor wires, which, while more easily fusible than platinum, can yet be employed up to a fairly high temperature.

3. For very high temperatures, carbon alone is available for the resistors of electric furnaces, and even the working lining of such furnaces is frequently constructed of carbon. The use of this element, while inevitable, introduces difficulties owing to its combustion when exposed to oxygen, and to its effect on the substances to be heated. In some cases a carbon tube serves at once as the resistor and the container of the material to be heated. For larger furnaces it is usual to employ granular carbon, or a number of plates of carbon pressed against each other, as the heating element ; the material to be heated being usually placed in a crucible or tube of carbon or magnesia.

4. In order to avoid the presence of carbon, a furnace * has been constructed that has a resistor tube made of the same material as the filament of a Nernst lamp. This tube only becomes an electrical conductor when raised to a red heat, and is therefore heated, in the first place, by an external coil of nickel wire.

For industrial use, carbon is usually employed as the resistor element, as in the Baily heating furnaces,† which are used for annealing German silver and similar materials. For such purposes, the electric furnace offers the advantages of compactness, absence of flues and trouble from burnt gases, ease of regulation and of maintaining a reducing atmosphere in the furnace.

Although they are used mostly for the heat treatment of steel, it is necessary to mention the furnaces that employ a liquid resistor such as fused salt in which pieces of metal can be heated quickly to a definite temperature.

ELECTRIC WELDING, SOLDERING, AND CUTTING APPLIANCES.

These have not been used to any great extent in non-ferrous metallurgy, being far more applicable to the treatment of iron and steel. Pieces of metal can, however, be welded or melted together, either by passing a large electrical current across the

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* J. A. Harker, *Electrochemical and Metallurgical Industries*, 1905, vol. iii. p. 273.

† T. F. Baily, *Metallurgical and Chemical Engineering*, 1915, vol. xiii. p. 557.

joint, or by means of an arc between electrodes of carbon or of the metal to be treated. Bars of metal can also be cut by means of the electric arc. Electrically heated soldering irons can be constructed and will prove very time-saving as compared with the ordinary variety. A recent development in electric welding is known as electro-percussive welding,* and is used for joining together two pieces of wire. The wires to be joined are held in suitable clamps, one of which slides down a guide so that the pieces of wire come into forcible contact. The clamps are connected through an inductance with a charged electrolytic condenser, and when contact takes place a large electrical discharge across the joint fuses and welds together the two pieces of wire.

ELECTRIC MELTING FURNACES.

The electrical melting of non-ferrous metals has not been practised to any great extent, but offers many advantages and will no doubt attain to some importance in the near future. Both arc and resistance furnaces have been used for this purpose.

Non-ferrous metals and alloys, such as copper, brass, tungsten, nickel or German-silver, can be melted very conveniently, and with little loss, in crucibles placed in carbon resistor furnaces, such as the Hoskins furnace which employs carbon resistor plates, or the Helberger furnace in which the crucible itself is made the resistor. The use of the Helberger furnace for brass melting has been described by H. G. Dorsey,† who finds it expensive and inconvenient on account of the short life of the crucible.

The Hering furnace,‡ also, operates on the resistance principle, but in this case the metal itself is the resistor, and this introduces difficulties in the case of metals like copper that have a high electrical conductivity. The induction furnace, also, can only have a limited application to the melting of non-ferrous metals, on account of their usually high electrical conductivity.

G. H. Clamer and Carl Hering § have described very fully the use of the Hering " pinch-effect " furnace for melting brass. The power consumption, when melting light brass or bronze chips, was found to be 250 kilowatt-hours per short ton of brass melted. This furnace was to be introduced at the foundry of the Ajax Metal Company in Philadelphia.

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* C. E. Skinner and L. W. Chubb, "Electro-percussive Welding," *Transactions of the American Electrochemical Society*, 1914, vol. xxvi. p. 149.

† H. G. Dorsey, "Tests on Electric Furnaces for Brass Foundries," American Institute of Metals, Sept. 1914, abstract *Metallurgical and Chemical Engineering*, 1914, vol. xii. p. 644.

‡ Carl Hering, "A New Type of Electric Furnace," *Transactions of the American Electrochemical Society*, 1911, vol. xix. p. 255.

§ G. H. Clamer and Carl Hering, "Electric Brass Melting," American Institute of Metals, Sept. 1914, abstract *Metallurgical and Chemical Engineering*, 1914, vol. xii. p. 648.

H. M. St. John has given information with regard to the electric melting of brass.* Two types of furnace were employed—the " crucible lift out " type and the tilting type. In the first of these the metal is melted in a crucible, which is then lifted from the furnace and carried to the mould. The tilting furnace contains no removable crucible, and the metal when melted must be poured into a ladle, and from that into the mould. In either case the furnace is of the electrical resistance type. He finds that with the tilting furnace, 280 kilowatt-hours are needed per ton of yellow brass, or 350 kilowatt-hours per ton of red brass, in continuous melting. If the power is only used for ten hours daily, the power consumption will be 400 and 500 kilowatt-hours respectively. With the crucible lift out furnace, the power consumption is approximately 43 per cent. more than the foregoing figures. He concludes that in melting yellow brass, the tilting electric furnace is more economical than the oil furnace, especially if continuous or twenty-hour operation is used.

For the economical melting of copper, brass, and other metals and alloys, the arc furnace appears to be the most efficient, but in arc furnaces there may be a serious loss, by volatilization, of metals like zinc, tin, and even copper, while the temperature is far less easily controlled than in the case of resistance furnaces.

A " medium temperature " arc furnace for melting brass and similar metals and alloys has been described by E. M. Schmelz.† The furnace is roughly cylindrical, and is provided with electrodes of the Stassano type.

The use of electric furnaces in the brass foundry was foretold by Moldenke ‡ more than ten years ago and, as has just been indicated, some advances have been made in this direction.

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* H. M. St. John, " Electric Brass Melting from the Central Station Viewpoint," American Institute of Metals, Sept. 1914, abstract *Metallurgical and Chemical Engineering*, 1914, vol. xii. p. 646.

† E. M. Schmelz, American Institute of Metals, Sept. 1914, abstract *Metallurgical and Chemical Engineering*, 1914, vol. xii. p. 645.

‡ R. Moldenke, " Electric Smelting for the Foundry," *Electrochemical and Metallurgical Industries*, 1907. vol. v. p. 42.

Another development that may prove important is the electrical melting of cathode copper.[*] As is well known, cathodes of electrolytic copper are sufficiently pure and need no further refining. In order to convert the cathodes into merchantable form, however, they must be melted, and in this operation the copper absorbs sulphur from the coal and oxygen from the air. To remove the sulphur more oxygen must be introduced, and finally this element must be removed with the assistance of carbon. In this way the mere melting of copper has rendered necessary an elaborate refining operation. If the electric furnace is used instead of the reverberatory the process will be much simplified, as both sulphur and oxygen can be satisfactorily excluded, and the process may therefore prove cheaper in spite of the higher cost of electrical heat.

Messrs. Lyon and Keeney review the furnaces available for the electrical melting of copper, and conclude that the Héroult steel furnace is the most suitable. The writer has had some experience of the Rennerfelt arc furnace,[†] and considers this to be perhaps the most promising type of arc furnace for melting copper, brass and the non-ferrous metals generally.

The Rennerfelt furnace [‡] has three graphite electrodes, one vertical and two horizontal, which meet in the middle of the furnace. These are supplied with two-phase current, the vertical electrode being the common return for the other two. With this arrangement an arc is produced which is projected, electromagnetically, downward towards the metal to be melted, acting as an electric blowpipe flame. This furnace, like Stassano's, has the advantage of an arc that is independent of the material to be melted, but the efficiency is better in this case, owing to the downward direction of the flame.

Conclusion.

The most important application of the electric furnace to non-ferrous metallurgy is for the electrolytic production of metals ; aluminium and sodium being the most notable examples. It seems probable that the field of electrolysis, even at high temperatures, has already been fairly well explored, but there is no doubt a considerable room for further development, and for the production of many of the less known metals on a large scale ; while even a common metal like zinc may be recovered economically by igneous electrolysis.

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[*] D. A. Lyon and R. M. Keeney, "Melting of Cathode Copper in the Electric Furnace," *Transactions of the American Institute of Mining Engineers*, 1914, vol. xlix. p. 724.

[†] A. Sahlin, "The Use of Liquid Ferro-Manganese in the Steel Process,' *Journal of the Iron and Steel Institute*, 1914, No. II. p. 213 "A Small-sized Electric Arc Furnace for Melting and Refining," *Metallurgical and Chemical Engineering*, 1914, vol. xii. p. 275.

[‡] A. Stansfield, "The Electrothermic Smelting of Iron Ores in Sweden," Report 344, Mines Branch, Department of Mines, Ottawa, 1915.

The electrothermic production of silicon, tungsten, chromium, vanadium, and many other metals is another important application of the electric furnace; but as these metals are generally produced in the form of ferro alloys, and are almost entirely used in the metallurgy of steel, this application does not fall clearly in the province of non-ferrous metallurgy. There is no doubt a wide field for extension and improvement in this branch of electric furnace operation.

The electric smelting of ordinary metals, such as lead, tin, zinc, copper, and antimony, has been taken up lately in view of the economies that should be obtainable in certain cases. Much work must still be done before the technique of these smelting processes can be perfected and before we can know how far the electric furnace can be effectively used in the production of these metals.

An important recent application of the electric furnace is for the melting and alloying of the non-ferrous metals. The practice has not yet become standardized, but there is certainly a great field for development in this direction.

Lastly may be mentioned the use of electrical heating methods for annealing, welding, and many other minor metallurgical operations. Great improvements have been made in the design and construction of such furnaces which will have an increasing use in the future.

The writer begs to acknowledge his indebtedness to the following gentlemen who have assisted him with data for use in the preparation of this paper : Professor J. W. Richards, Mr. F. J. Tone, Mr. R. Turnbull, Mr. R. S. Wile, Dr. J. A. Mathews, Mr. T. H. Wardleworth, the American Vanadium Company, and the Primos Chemical Company.

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